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Last Name	First Name	Middle Initial	Residence (City/State/Country)
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Title: **"METHOD AND APPARATUS FOR MULTIPLE TARGET CLASS DATA RECORDING, PROCESSING AND DISPLAY FOR OVER THE HORIZON RADAR "**

Enclosed are:

☒ 10 pages of the specification (including description)
☒ 5 sheet of drawings
☒ 1 page Abstract
☒ A verified statement to establish small entity status under 37 CFR 1.9 and 37 CFR 1.27.
☐ The invention was made by or under a contract with the following agency of the United States Government: ______under Government contract number _____.

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U.S. PROVISIONAL PATENT APPLICATION

METHOD AND APPARATUS FOR MULTIPLE TARGET CLASS DATA RECORDING, PROCESSING AND DISPLAY FOR OVER THE HORIZON RADAR

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FIELD OF INVENTION

[01] The invention relates to over-the-horizon-radar (OTHR). More specifically, the invention relates a method and apparatus for enabling OTHR to simultaneously track multiple target types.

BACKGROUND OF THE INVENTION

[02] OTHR is a well established and economical, long-range, wide-area surveillance sensor technology. OTHR propagates high-frequency (HF) energy via the ionosphere to detect targets at distances of roughly 400 to 2000 nautical miles (nmi) from the radar, within azimuthal sectors nominally 64° wide. Operational OTHRs have been deployed at various locations in the United States and Australia for target detection applications, and the underlying technology is well described in the literature of the art, for example in, J. M. Headrick and M. I. Skolnik, "*Over-the-Horizon Radar in the HF Band*," Proc. IEEE, vol. 62, no. 6, pp. 664-673, 1974; T. W. Washburn, L. E. Sweeney, Jr., J. R. Barnum, and W. B. Zavoli, "*Development of HF Skywave Radar for Remote Sensing Applications*," in AGARD Conf. Proc. No. 263, Special Topics in HF Propagation, V. J. Coyne, Ed. London, England: Tech. Editing and Reproductions, 1979, ch. 32.; and James R. Barnum, "*Ship Detection with High-Resolution HF Skywave Radar*," IEEE Jour. Oceanic Engineering., Vol. OE-11, No. 2, pp. 196-209, April 1986.

[03] Current OTHRs must deal separately with targets found in different classes, where the classes are defined by differing speeds and accelerations. The history of development of OTHR, directed at one new target class after another, has spawned unique methods for radar operation and signal processing to achieve optimal results on each class. For example, the radar system must be configured with short dwell periods for fast targets, or with long dwell periods for slow targets that compete with stochastic earth clutter. Although the target application or "mode" can be switched rapidly, a deployment scenario involving detection of slow targets can preclude detection of a faster target altogether, and vice versa. Even some medium speed target detection modes have a target refresh rate that is much too slow to acquire and identify high speed, high acceleration targets.

[04] The OTHR community has long recognized the limitation imposed by differing radar requirements for each target class. Proposed solutions have been prohibitively expensive (deploying multiple radars), or have reduced capability (split radar operation).

[05] There is therefore a need in the art for a method and apparatus to enable detection of multiple target classes by a single OTHR installation.

BRIEF DESCRIPTION OF THE DRAWINGS

[06] Fig. 1 is a diagram of the geometry of a typical OTHR deployment.

[07] Fig. 2 is a schematic diagram of OTHR propagation.

[08] Fig. 3 is a diagram of an exemplary conventional OTHR control and processing system.

[09] Fig. 4 is a flow diagram of a method according to the present invention.

[10] Fig. 5 is a schematic diagram of an exemplary multi-class OTHR according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Over The Horizon Radar

[11] Figure 1 depicts the geometry of a typical OTHR system 100. The transmitter 110 and receiver 120 are separated by 50 to 100 nmi to provide isolation during the use of continuous waveforms, such as frequency-modulated continuous-wave (FMCW). The transmit and receive sites are both controlled by the Operations and Control Center (OCC), which is preferentially located with the receiver. By means of a midpath ionospheric reflection, the radar system is able to access a coverage area that is depicted in by the larger sector 130, which is called the "primary coverage area" (PCA). This sector is nominally 64° wide and ranges from approximately 400 nmi, to as much as 2,000 nmi, from the radar.

[12] Operations at single radio frequencies are concentrated in "dwell-illuminated regions" (DIRs), as depicted by the smaller sectors 140 containing targets as shown in Figure 1. A radar dwell is defined here as the time required to search a specific area that nominally measures on the order of 100 nmi in azimuth and 200 nmi in range. A typical OTHR defines a dwell for a single coherent integration time (CIT), which encompasses 16 parallel finger beams spaced nominally by 0.5 deg. An alternate DIR embodiment consists of 3, 4, 5, 10, 15, or 20 parallel finger beams spaced by 0.5 deg, that is covered up to 5 at a time using sequential CITs. Thus, a DIR consists of multiple smaller "resolution cells" with dimensions proportional to the radar's antenna beamwidth and range resolution, and typically measures on the order of 10 x 10 nmi, or smaller in the range dimension. Target detections within a DIR are filtered and smoothed with time by an automatic tracker to enable positioning accuracy much better than a resolution cell size. As the figure suggests, OTHR is a "look-

down" radar, with elevation angles on the order of 5 to 20 deg, which tends to mitigate the problem of target shadowing during terrain following maneuvers in mountainous canyons.

[13] A two-dimensional schematic of OTHR propagation 200 is shown in Figure 2, and for simplicity the path is shown monostatically. (The differences in the transmit and receive paths for the bistatic radar are accounted for by the radar's tracking system.) The radar system constantly sounds the ionosphere 210, both directly over the radar by means of a quasi-vertical ionogram (QVI) and out to target distances with the wide-sweep backscatter ionogram (WSBI).

[14] These soundings, which are part of an OTHRs Propagation Management and Assessment (PMA) function, are used to update an on-line ionospheric model that provides the system with the available ionospheric layers, modes, and radio frequencies for operation. (U.S. OTHRs avoid several frequency bands, such as amateur and maritime mobile, and they operate strictly on a not-to-interfere basis with other HF users.) The radar waves illuminate the desired footprint location (i.e., DIR) at a single frequency computed from the on-line ionospheric model. The radar paths to the near and far ends of the DIR are depicted as perfect triangles, with an apex at the path "virtual height." The triangle path to the center of the footprint is used as the basis for estimating ionospheric height in the PMA function for all targets in a DIR. In fact, the wave refracts gently through the ionosphere, as depicted by the center triangle. Martyn's Equivalent Path Theorem (*circa* 1935) (see K. Davies, "*Ionospheric Radio*", Peter Peregrinus Ltd., London, 1989), with a correction for curved ionosphere, assures us that we may draw the equivalent triangle and correctly compute propagation time delay assuming free space propagation. Ionospheric tilts (horizontal variations in electron density) modify the propagation paths slightly, but not significantly, under most circumstances. Variations in virtual height across a DIR likewise are minimal (but can be accounted for if needed).

[15] Radar energy is backscattered from the ground, targets (elevated or not), meteors exploding in the ionosphere, and occasionally from dynamic irregularities in the ionosphere itself. The ground backscatter constitutes the majority of radar clutter, which is normally at least 30 to 70 dB stronger than an aircraft target in any given range-azimuth cell. The targets are separated from the clutter, and detected against the much weaker atmospheric noise level, by virtue of Doppler processing. This processing takes advantage of the physical change in

radar frequency caused by a moving target, much the same as the change in pitch of a train whistle as the train passes an observer standing near the track. The frequency is lower if the target (or sound source) is moving away, because its range rate tends to *stretch* the wave with time (and a longer wavelength means a lower frequency with a fixed speed of propagation). The reverse is true for an approaching target (or sound source). The Doppler processing also reduces the amplitude of occasional random backscatter from moving ionospheric irregularities, called "spread clutter," that was discussed and illustrated by Lucas, Pinson, and Pilon in "*Some Results of RADARC-2 Equatorial Spread Doppler Clutter Predictions*", Proc. 7th International Ionospheric Effects Symposium, 1993.

[16] A routine on-line measurement of radar performance is called the sub-clutter visibility (SCV), which is the ratio of average land (or sea) clutter amplitude to the average noise power. It has been found empirically at WARF that a median SCV $\geq$ 50 dB over land is required for reliable detection and tracking of single- and twin-engine private aircraft. The required SCV over the ocean is typically 10 dB higher, because the ocean clutter is 10 dB stronger than the land clutter, on the average. Similar minimum SCVs are required for missile detection, although the latter is also critically dependent on radio frequency because the targets are more highly resonant. The on-line measurement of SCV (and other factors, particularly the Doppler spread of clutter) enables the OTHR to continuously monitor its expected performance and, when necessary, change its operating frequency or move its coverage area to achieve acceptable performance. SCV is proportional to transmitter power (in the absence of spread clutter), and it has been found in the recent research that, with the antenna gains employed by modern OTHRs, a transmitter power of 20 kW is the lowest level advisable for general applications.

[17] A target is detected with "slant-space" parameters of round-trip time delay, azimuth, and Doppler shift. The automatic tracking system associates and filters the slant-space detection strings to form smooth and independent tracks. It is then the duty of PMA to convert the spatial parameters of each detection string in bistatic radar space to equivalent earth coordinates. The on-line ionospheric model derived from the soundings is used to resolve this geometry, which enables the estimation of geographic position, course, and speed for each target. These earth-normalized (geographically positioned) tracks are updated and redisplayed during radar scanning, and each update is reported to the user.

Traditional OTHR Processing

[18] Figure 3 depicts a functional block diagram of an exemplary conventional OTHR control and processing system 300. Precise timing is ensured by the use of Cesium clocks 310, or in alternate embodiments by means of GPS slaved oscillators. The important features of the conventional architecture for the present purpose are the controller 320, waveform generator 330, data acquisition and signal processor 340, and tracking system 350. All of these components are specifically designed and implemented to detect and track a single target class at any one time: there is no capability to track multiple target classes as contemplated in the present invention.

Multiple Target Tracking

[19] The inventive method 400 for performing multiple target-class tracking is depicted in figure 4. The method starts at step 405 and proceeds to step 410.

[20] At step 410, the OTHR is tasked in staring mode, whereby the radar beams are not scanned, but are fixed so as to cover a specific area of interest. This DIR area is preferentially of the order of 6,000 to 32,000 square nautical miles, depending on number of beams and center range, and preferentially uses a nominal frequency modulated continuous wave (FMCW) up-chirp waveform. Useful waveform alternates that permit Doppler processing include FMCW down-chirp, FMCW triangle-chirp, simple pulse, phase-coded pulse, and linear-frequency-modulated pulse (also known as interrupted FMCW).

[21] At step 420, the bandwidth (BW) and waveform repetition frequency (WRF) are set. The WRF is chosen such that it is high enough to display Doppler shifts from fast targets, including allowance for Doppler aliasing into adjacent range bins when necessary, with minimal eclipsing loss when the target Doppler crosses the clutter at multiples of the WRF. The unambiguous range for a WRF of 30Hz is 5,000km (2,700 nmi), which is high enough to avoid unwanted ionospheric clutter. Slower targets tend to have Doppler shifts less than 5Hz, which is a subdivision of the unambiguous ± 15Hz normally displayed by this WRF. The BW must be small enough to avoid radio frequency interference (RFI), both to and from other HF band users, large enough to provide clutter cell reduction and useful target position accuracy, but not so large that targets can cross a range cell during a CIT (distance = radial velocity x CIT). Past OTHR research indicates that a BW of 25kHz (3.2 nmi range per cell) enables a modest clutter reduction for slow targets, is generally realizable in the midst of radio

frequency interference, and has range resolution that does not smear the faster targets during a coherent integration time (CIT). Typical CITs for exemplary target classes, described in terms of speed and acceleration, are:

Speed	**Acceleration**	**CIT**
0-50 m/s	negligible	26s / 6.50s advance
50-500 m/s	0-1 g	2-8s / 1.00s advance
500 – 2000 m/s	1-3 g	2-4s / 0.50s advance
Up to 8000 m/s	Large	2s / 0.25s advance

[22] At step 430, the backscattered echoes from the area of interest are time-delay gated and dechirped (demodulated) by the radar receiver, sampled using an analog-to-digital converter (ADC) and then buffered for parallel stream processing. The buffering may, in some embodiments, involve the copying of data so that processing for each target class is performed from an independent buffer. Alternate embodiments may use a single buffer and multiple pointers into said buffer.

[23] At step 440, the buffered data is processed independently for each target class. Processing comprises decimation in range and/or Doppler time domains (if required), range-Doppler (RD) map generation, impulsive noise excision (INE), RD normalization, and automatic peak detection. Preferred embodiments of the invention will utilize a separate user display for each processed target class.

[24] Preferred embodiments will further include automatic tracking as part of the processing of step 440. A multiple-hypothesis tracking (MHT) algorithm with Kalman filtering (for background, see Samuel S. Blackman, "*Multiple Hypotheses Tracking for Multiple Target Tracking*," IEEE A&E Systems Magazine, Vol. 19, No.1, Part 2: Tutorials, January 2004) may be used, with unique target models and Kalman association parameters as appropriate for each target class. For example, azimuthal wander due to traveling ionospheric disturbances must be carefully smoothed for ships and land vehicles, but less so for fast targets; significant acceleration allowance is needed for missiles. The output of the automatic tracking processing is preferentially displayed on a single geographic situation display.

[25] The method is then complete at step 445.

[26] Figure 5 depicts an exemplary OTHR system embodiment 500 according to the present invention, comprising an OCC tasking menu 510, a transmitter 520, a receiver 530, radar data processing elements 540, heads up detection displays 550, automatic tracking

elements 560 and a multi-target geographic situation display 570. Although the exemplary embodiment 500 is depicted having three processing paths, representing three different target classes, the figure should not be interpreted to limit the invention to three processing paths – any number of processing paths greater than one is within the scope of the invention. It is further contemplated that the radar data processing elements 540 and the automatic tracking elements 560 may use either special purpose hardware, in which one device may be allocated per target class, or may use general purpose computing hardware, with either a single or multiple processors. Preferred embodiments will use general purpose computing elements, with multiple processors contained therein, allowing for parallel processing of each target class.

[27] The OCC tasking menu 510 allows the operator of the OTHR to input the parameters for operation. The number of target classes is input (within the scope of available processing hardware), and the CIT and advance for each class. Further, the waveform parameters WRF and BW are provided, along with the area of interest to which the radar should be aimed.

[28] The transmitter 520 receives the parameters from the OCC tasking menu and transmits the specified waveform continuously, with the beam steered toward the specified area of interest.

[29] The receiver 530 receives the backscattered echoes from the area of interest, and processes them by time-delay gating, dechirping, and sampling (using an analog to digital converter). The samples are then buffered into streams for each target class, the present example depicting three streams.

[30] The radar data processing elements 540 are chosen according to the target classes defined from the OCC tasking menu. The processing undertaken in each radar data processing element 540 comprises decimation in range and/or Doppler time domains (if required), range-Doppler (RD) map generation, impulsive noise excision (INE), RD normalization, and automatic peak detection.

[31] The output of the radar data processing elements 540 is passed to a plurality of heads up detection displays 550. Preferentially, one display is provided for each target class, although alternate embodiments may omit particular (or all) displays 550.

[32] The output of the radar data processing elements 540 is also passed to a plurality of automatic tracking elements 560. A multiple-hypothesis tracking algorithm with Kalman

filtering may be used, with unique target models and Kalman association parameters as appropriate for each target class.

[33] The output of the automatic tracking elements 560 is, in preferred embodiments, displayed on a single geographic situation display 570, used to plot target progress on a digital map. The multiple target class processing of the present invention enables accurate computation of target vectors, as the ionospheric conditions will be the same for each target. Previous target vectoring has suffered inaccuracy due to the sequential approach to radar operation, with long dwells for slow targets, interspersed with short dwells for air targets.

Operational Utility

[34] Modern counternarcotic, counterterrorism, and similar early-warning attack threat scenarios bespeak the need for radar acquisition and *simultaneous* tracking of diverse target types. OTHR is the only wide-area sensor that is capable of remote detection and tracking of all target classes. However, Modern OTHRs are capable of being configured and tasked to detect only one class at a time. Concentration on one target class alone can miss important targets in another class. For example, for targets in the 50-500 m/s range, the radar dwells are relatively short (2-4 s), so that target updates will be acquired more frequently to facilitate tracking, and Doppler smearing due to acceleration and speed fluctuations will be minimized. These short dwells are typically updated no more often than once per second. Very fast (500-1000m/s) with high acceleration, however, require much more frequent target updates (on the order of 0.25 to 0.5 s) are necessary to detect and track. Conversely, slow targets (0-50m/s) , must be detected and tracked in the earth clutter echo, which requires much longer radar dwells, on the order of 25 s.

ABSTRACT OF THE DISCLOSURE

[35] A method and apparatus are disclosed that enable an over-the-horizon-radar (OTHR) system to detect and track multiple target classes simultaneously, where target classes are defined by the speed and acceleration of the tracked objects. The OTHR is tasked in a staring mode, with a bandwidth and waveform repetition frequency that enable detection of Doppler shifts from all target types, with sufficient clutter reduction and range resolution. The backscattered echoes are buffered for each target class and processed independently. The output of an automatic tracking algorithm then preferentially plots target progress on a single digital map for all target classes.

Fig. 1

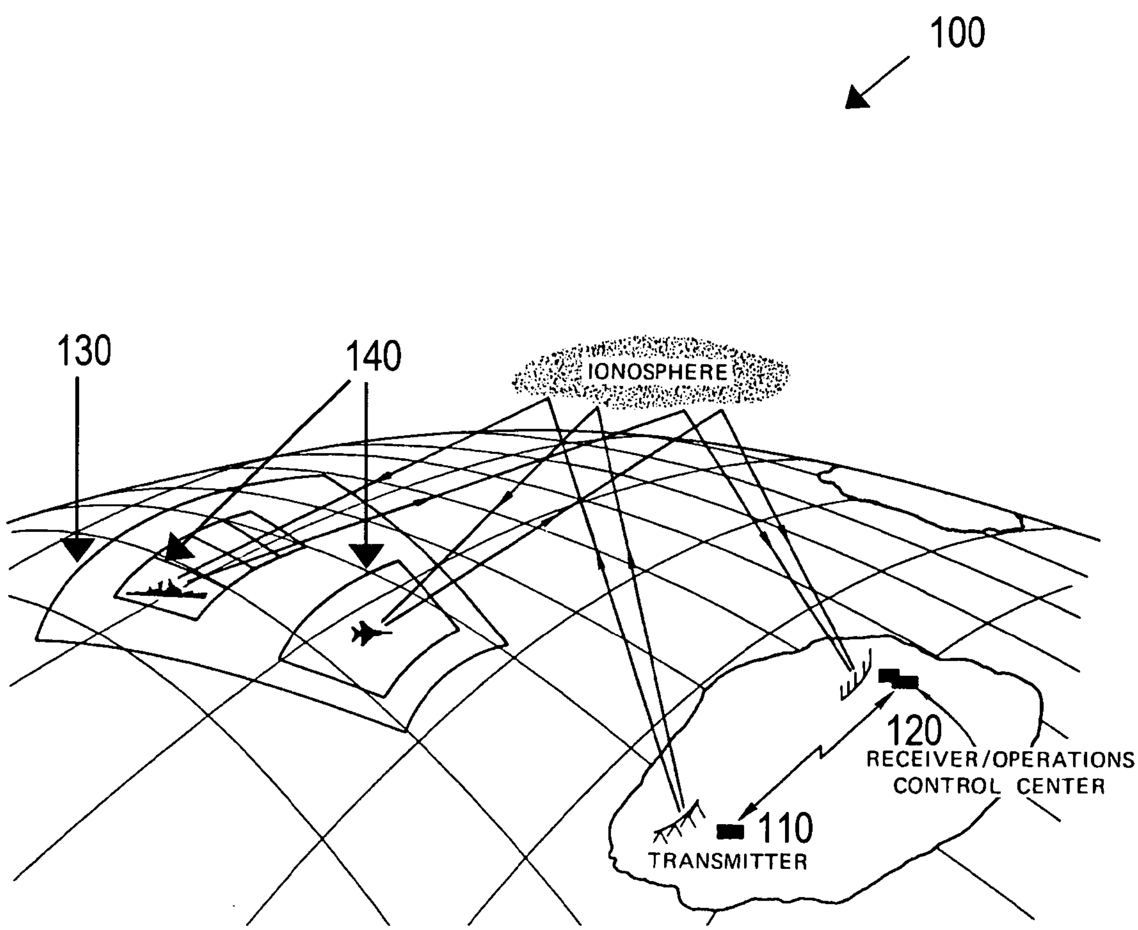
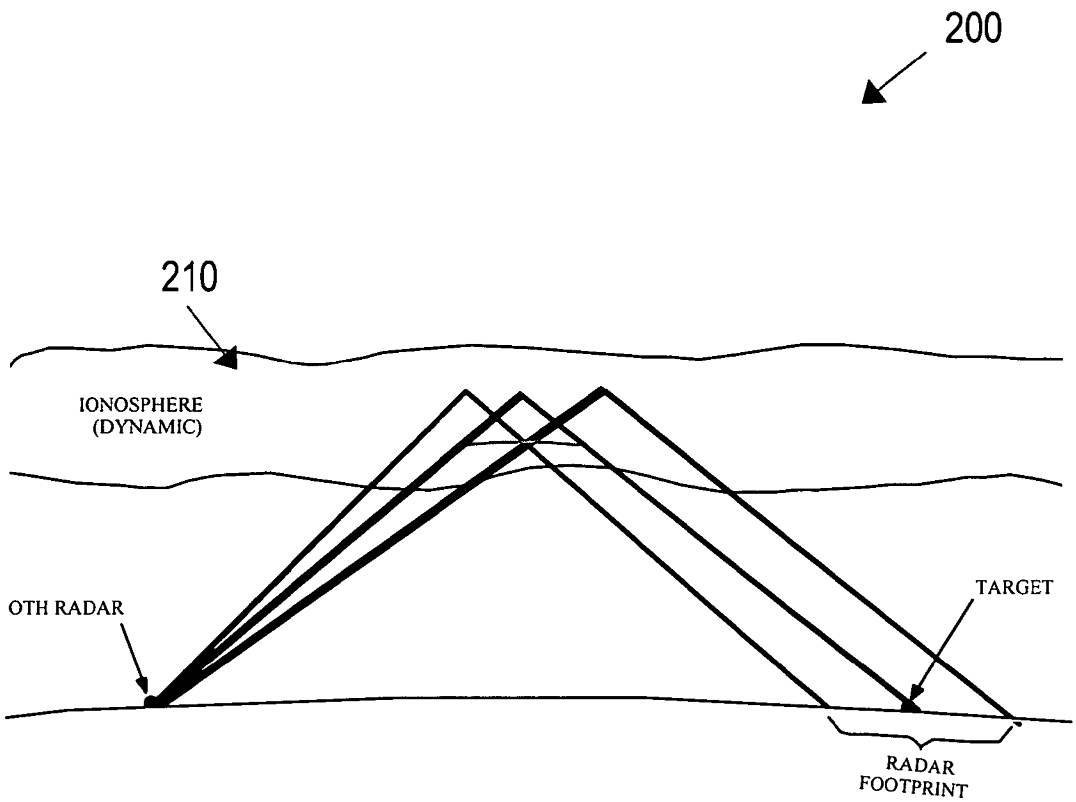

100
130
140
IONOSPHERE
120
RECEIVER/OPERATIONS CONTROL CENTER
110
TRANSMITTER

Fig. 2



SELECT OPERATING FREQUENCY

⇑

RADAR MEASURES

- TIME DELAY
- AZIMUTH
- DOPPLER

⇒

USES IONOSPHERIC DIAGNOSTIC MEASUREMENTS TO DETERMINE REFLECTION HEIGHT

⇒

CONVERTS TO TARGET TRACK PARAMETERS

- EARTH COORDINATES
- TARGET COURSE AND SPEED

Fig. 3

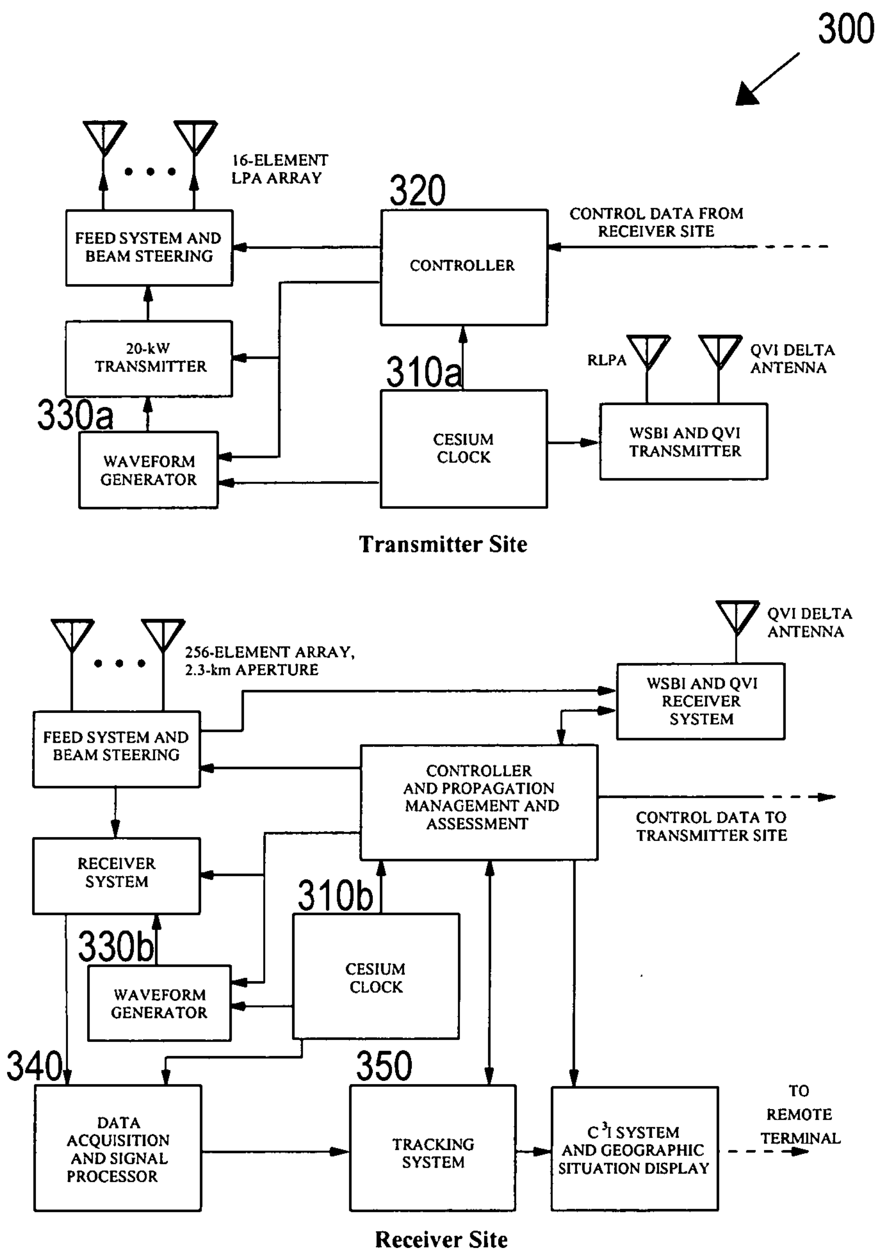

300
16-ELEMENT LPA ARRAY
320
CONTROL DATA FROM RECEIVER SITE
FEED SYSTEM AND BEAM STEERING
CONTROLLER
20-kW TRANSMITTER
310a
RLPA
QVI DELTA ANTENNA
330a
WAVEFORM GENERATOR
CESIUM CLOCK
WSBI AND QVI TRANSMITTER
Transmitter Site
QVI DELTA ANTENNA
256-ELEMENT ARRAY, 2.3-km APERTURE
WSBI AND QVI RECEIVER SYSTEM
FEED SYSTEM AND BEAM STEERING
CONTROLLER AND PROPAGATION MANAGEMENT AND ASSESSMENT
CONTROL DATA TO TRANSMITTER SITE
RECEIVER SYSTEM
310b
330b
CESIUM CLOCK
WAVEFORM GENERATOR
340
350
TO REMOTE TERMINAL
DATA ACQUISITION AND SIGNAL PROCESSOR
TRACKING SYSTEM
C³I SYSTEM AND GEOGRAPHIC SITUATION DISPLAY
Receiver Site

Fig. 4

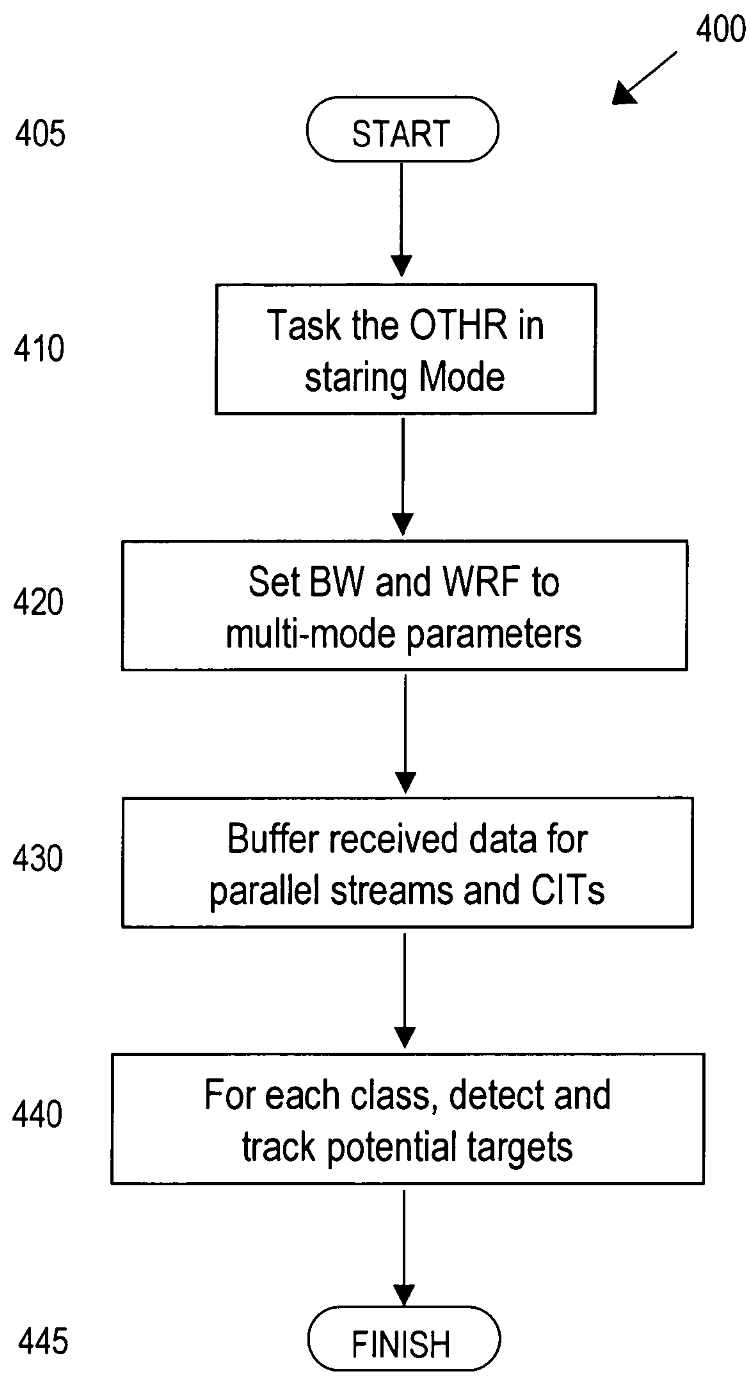
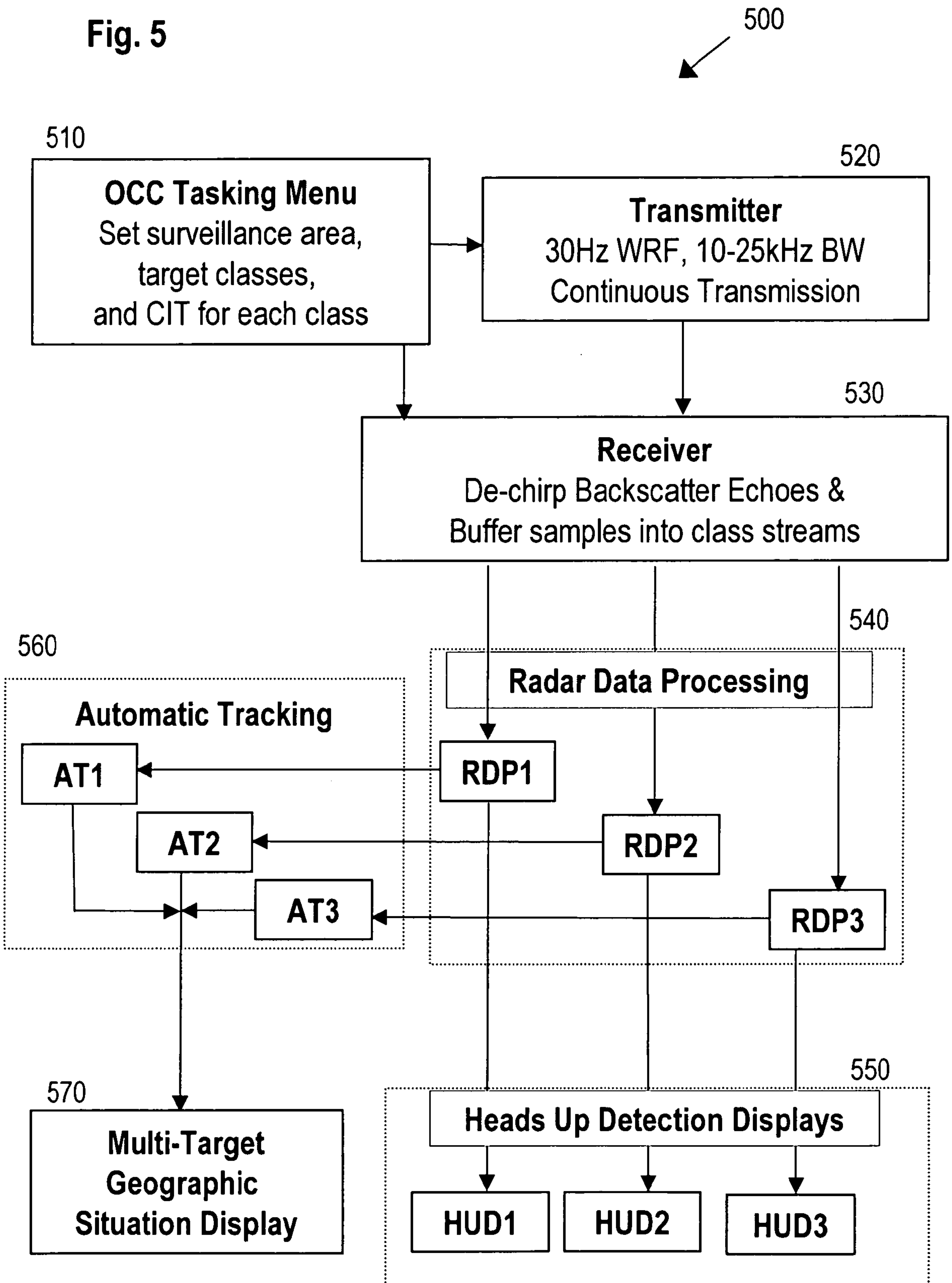

400
405
START
410
Task the OTHR in staring Mode
420
Set BW and WRF to multi-mode parameters
430
Buffer received data for parallel streams and CITs
440
For each class, detect and track potential targets
445
FINISH

Fig. 5


500
510
OCC Tasking Menu
Set surveillance area, target classes, and CIT for each class
520
Transmitter
30Hz WRF, 10-25kHz BW
Continuous Transmission
530
Receiver
De-chirp Backscatter Echoes &
Buffer samples into class streams
540
Radar Data Processing
RDP1
RDP2
RDP3
560
Automatic Tracking
AT1
AT2
AT3
570
Multi-Target Geographic Situation Display
550
Heads Up Detection Displays
HUD1
HUD2
HUD3

STATEMENT CLAIMING SMALL ENTITY STATUS
(37 CFR 1.27(a)(3))--NONPROFIT ORGANIZATION

Applicant: **SRI INTERNATIONAL**
Application No.: Not Yet Known **Filed:** April 5, 2004
Title: METHOD AND APPARATUS FOR MULTIPLE TARGET CLASS DATA RECORDING, PROCESSING AND DISPLAY FOR OVER THE HORIZON RADAR

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CITATION OF STATUTE **California Corporations Code Section 5110, et seq.**

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SIGNATURE ____________________ DATE April 5, 2004